Optimising Indonesia’s Electricity Market Structure

Hakam, Dzikri; Macatangay, Rafael

Published in:
Proceedings - 2018 IEEE International Conference on Industrial Technology, ICIT 2018

DOI:
10.1109/ICIT.2018.8352360

Publication date:
2018

Optimising Indonesia's electricity market structure: Evidence of Sumatra and Java-Bali power system

[1]Dzikri Firmansyah Hakam, [2]Rafael E. Macatangay
Centre for Energy, Petroleum and Mineral Law, and Policy
CEPMLP, University of Dundee
Scotland, United Kingdom

[1]Dzikri Firmansyah Hakam
Perusahaan Listrik Negara
PT. PLN (Persero)
Jakarta, Indonesia

***Abstract*— This research focuses on modelling large-scale power system using DC load flow approach in Indonesia electricity market which consists of two primary power system, i.e. Java-Bali and Sumatra power system. This chapter adopts the 26 nodes stylised model for Java-Bali power system and eight nodes stylized model for Sumatra power system, by incorporating generation, transmission and power system stability constraint. The study in this chapter is the first electricity market modelling to study Java-Bali and Sumatra power system using perfect competition and oligopoly strategic behaviour.**

This paper simulates the effect of electricity market restructuring in power generation market in Indonesia power system. By using market modelling, i.e. perfect competition and Cournot oligopoly market, this chapter determines the optimal market structure, effective generation mix in the generation companies, and an effective number of competitive electricity market. This preventive approach contributes to the current literature in electricity market modelling and market power studies, which is essential for Indonesia, when and if the market restructuring occurs.

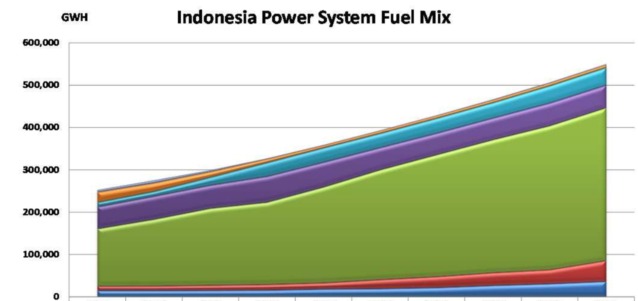
Keywords—DC load flow, perfect competition, Cournot, market power, Java-Bali, Sumatra

I. INDONESIA POWER SYSTEM OVERVIEW

A. Indonesia's power generation system

The total generation capacity of Indonesia power system year 2015 is 40.533 MW with the Java Power system as the most substantial power system (total capacity 31.815 MW) and Sumatra power system as the second largest power system (total capacity 6,283 MW). Energy mix in Indonesia power system - from the biggest to smallest portion- consist of coal, gas, diesel (HSD and MFO), hydro, geothermal, and solar. System operator dispatches PP based on the characteristic of generation technology, i.e. baseload PP, intermediate PP and peaking PP.

As can be seen in Figure 1 below, power generation in Indonesia power system is dominated by Coal-fueled power plants since coal has a low cost compared to oil and gas. Power system dispatcher utilises coal PP as baseload generation which makes a high capacity factor of coal PPs close to 100 %. Gas is the second largest energy in the fuel mix that plays a vital role as intermediate PP to balance the energy mix. Gas PP and CCGT PP have a high ramping rate characteristic that can adjust the electricity demand more flexible than coal, hydro (run-off river) and geothermal PP. According to the ramp-up and ramp-down characteristics and fuel cost profile, Indonesia power system utilises coal and geothermal PP as baseload PP; gas PP as intermediate PP; diesel and peaking hydro PP as peak load PP.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Import	758	929	1,063	1,582	1,367	1,397	1,172	1,578	1,487	1,503
Biomass	37	50	50	50	50	50	50	50	50	50
Solar	4	4	5	6	6	6	6	7	7	7
MFO	4,834	5,895	3,090	669	644	575	623	690	772	953
HSD	24,004	19,812	12,879	8,250	5,654	5,791	5,882	5,892	6,229	6,568
LNG	10,465	11,094	18,613	32,235	33,640	33,400	34,844	36,388	40,673	41,105
Gas	52,140	54,915	54,833	61,170	58,962	52,525	51,184	51,374	53,747	53,625
Coal	135,264	157,356	181,660	194,003	225,904	259,470	287,629	313,880	340,198	361,131
Geothermal	10,694	11,067	12,550	13,860	15,133	21,391	26,508	30,742	33,395	49,353
Hydro	14,502	14,468	14,749	15,383	17,902	18,916	21,108	26,136	30,200	35,876

Figure 1. Indonesia fuel mix 2015-2024 [6]

The renewable energy source in Indonesia power system consists of hydro, solar, biomass and geothermal. Based on PLN's energy system dispatching, the role of green energy is not as significant as gas and coal. However, Indonesian government already committed to extending the green energy utilisation to 20% of the total energy mix in 2024 [6]. Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) will gradually replace natural gas utilisation in the power system.

Peaking PP is utilised with low CF (Capacity Factor) for peak load time. The merit order of peaking PP is based on the flexibility of generation technology (ramp-up and ramp-down) and also fuel price. The merit order of peaking PP in Indonesia power system, from the highest to the lowest marginal cost respectively, is as follow: diesel PP, CNG and LNG gas-fueled PP, pumped storage PP, runoff river PP. Pumped storage PP takes a more extended construction period compare to diesel and gas PP. In another hand, gas-fueled PP is considered the most optimal replacement for diesel PP since CNG and LNG PP have a high ramping rate and a short period of project instalment. However, the significance of gas power plant to substitute diesel PP in filling peaking load resulted in serious power system problem since coal PP could not substitute the role of gas PP as intermediate PP (coal PP has a low ramping rate and flexibility to the load fluctuation in the system). Table 1 below shows the operational cost of a power plant in Indonesia which indicate the merit order of the generation technology.

TABLE 1 POWER GENERATION COST IN INDONESIA (2015)

Generation Technology	Operational Cost (IDR/KwH)				
	Fuel	**Maintenance**	**Depreciation**	**Misc.**	**Employee**
Hydro PP	21.29	30.8	81.62	4.08	18.09
Coal PP	626.25	62.46	112.93	1.96	6.54
Diesel PP	2308.6	555.27	180.94	17.7	104.08
Gas PP	2135.8	66.39	145.34	2.82	12.59
Geothermal	1015.9	17.26	70.63	1.81	15.87
Steam Gas	884.31	44.07	66.36	3.02	4.05

B. Indonesia's power transmission system

The transmission network of Indonesia power system is not a single interconnected system but consist of the multi-power system. This archipelago characteristic implicated in a unique inter-island and inter-subsystem transmission constraints that resulted in a sophisticated electricity market modelling and analysis more challenging. The characteristic of Indonesia that consists of approximately 17,000 islands determines the critical features of Indonesia electrical system transmission. The electricity demands are scattered in thousands of islands which are isolated and not connected by overhead/submarine transmission lines. Interconnection transmission system is limited in inter-island networks, e.g. Java-Bali, Sumatra, Sulawesi, Kalimantan, and Lombok. Power system dispatcher operates these power systems at 70 kV, 150 kV, 275 kV and 500 kV. The Java-Bali power system consists of 70 kV, 150 kV, and 500 kV while Sumatra system consists of 70 kV, 150 kV, and 275 kV. PLN operates power system frequency at 50 Hz for all Indonesia regions.

Sumatra power system is based on 150 kV network and divided into two significant subsystem, which is North Sumatra subsystem and Mid-South Sumatra subsystem. North Sumatra subsystem consists of three smaller subsystems, i.e. Aceh and Sumut subsystems while Mid-South Sumatra consists of West Sumatra, Riau, Jambi, Bengkulu, South Sumatra and Lampung subsystems. On the other hand, Java-Bali power system modelling is based on 500 kV super grids which consist of four primary subsystems, e.g. Jakarta-Banten, West Java, Central Java, East Java-Bali subsystem.

C. Indonesia's Electricity demand

Indonesia power system has unique characteristics compared to the power system in other countries. The power system load of Indonesia is dominated by residential consumers that effect in lower load factor. The lower power system load factor is resulting in a more substantial load delta between base and peak load. The generation system is developed according to the fluctuation of the system peak load, and not the system base load. Thus, the more significant load delta in Indonesia power system resulted in a low capacity factor of peaking generation technology. However, Indonesia power system planning should cover a more substantial portion of peaking PP to accommodate the shifting period of base load to peak load in the power system. Table 2 shows the list of load factor forecast of Indonesia's power system interconnections.

TABLE 2 LOAD FACTOR IN INDONESIA POWER SYSTEM

No	Power System	LF 2015 (%)	LF 2024 (%)
1	Java-Bali	79	80
2	Sumatra	69	77
3	West Kalimantan (Kalbar)	66	66
4	South-Southeast-East-North	67	68
5	South Sulawesi	68	69
6	North Sulawesi	68	73

D. Indonesia's electricity law and policy

The participation of private parties in Indonesia's electricity supply industries started by the enactment of the 1985 Electricity Law. The private parties acted as IPPs and restricted to supply electricity to PLN in limited capacities under PPAs (Private Purchased Agreements). In 2002, the private parties could participate in the electricity industry not only in generation business but also in the retail business under the 2002 Electricity Law. Since the adoption of the 2002 Electricity Law, electricity policy decision gradually moving towards fully functioning competitive market. The electricity market regulator removes the electricity price subsidy in stages to achieve clear market signal and price.

The 2002 Electricity Law was invalidated by the Indonesia Constitutional Court in 2004 since it was deemed unconstitutional, return to the 1985 Electricity Law. Indonesia Constitutional Court considers electricity as a social necessity. Therefore, the electricity business should be exclusively delivered by PLN as stated owned company. According to Indonesia's constitution, the electricity sector is one of the critical areas of the state. Thus, its business activities, e.g. generation, transmission, and distribution should be aligned with the Indonesia Constitution year 1945 Article 33 paragraph 2. The constitution states that "Production branches significant to the state and anything controlling the life of many people shall be controlled by the State".

Indonesia electricity market is in the middle of profound changes. The current electricity framework is regulated by the Electricity Law No.30 year 2009 (the 2009 Electricity Law). In 2009, Indonesia's government passed the 2009 Electricity Law that contains the primary principle of the 2002 Electricity Law regarding the participation of private parties in the electricity business. Based on the 2009 Electricity Law, Indonesia adopts competition in the generation through the participation of private players in the market. Thus, there is a portion of the power plants that belong to private companies (IPPs) and state-owned companies (IP, PJB, and other PLN PP). The 2009 Electricity Law gives a more prominent role to the regional governments to build electricity infrastructure and to determine electricity tariffs. According to the 2009 Electricity Law Article No. 4 Point 1, the regional and central government are responsible for securing the electricity supply through PLN. The 2009 Electricity Law is expected to guide the liberalisation process of Indonesia's electricity sector through the participation of private companies in the power generation business (See the 2009 Electricity Law Article No.4 Point 2).

According to the existing electricity Law in Indonesia, the private entities may participate in power supply business that covers power generation, transmission, distribution and sale to the consumer. However, at present, the transmission and distribution sectors are exclusively owned and operated by PLN while the portion of IPPs is still limited. Transmission and distribution network is operated by PLN transmission and PLN distribution respectively, while transmission system is operated by PLN TSO's (P2B and P3BS).

Indonesia's electricity development plant is constituted in The National Electricity Supply Business Plan (RUPTL) 2015-2024 [6]. [6] is designed to provide reliable and sustainable electricity to the consumer. PLN (2015) consists of electricity demand forecast, generation expansion planning and transmission-distribution system planning. The generation planning in [6] is according to the least cost principle and power system reliability optimisation. RUPTL is planned and reviewed annually to accommodate yearly changes in the assumption of RUPTL and the delays of power plant's Commercial Operation Date (COD). [6] is formulated by PLN based on the specific criteria of the National Electricity Master Plan (RUKN) from the Ministry of Energy and Mineral Resources.

II. METHODOLOGY

The steps in optimising electricity market structure of this paper are based on the theoretical model in [7] and [8]. The DC load flow calculation is based on the research by [9]–[11] while the modelling of perfect competition and Cournot competition are already widely applied in electricity market modelling as in [12]–[15]. The calculation of elasticity of demand of each node is following [12].

The first step is to model the Sumatra and Java Bali power system using Perfect competition and Cournot competition according to the network congestions, load profile (LDC), energy mix and reserve margin. The second step is calibration step that adjusts the model coherent with power system realisation in [16], [17]. The third step is to apply power plant merger analysis to calculate possible market structure configuration. The final step is to conduct market power assessment using Residual Supply Index according to [18]–[20]. [20] stated that RSI between 120-150% is a reasonable competitive market. In a power system where market power index is below the threshold, the optimal market structure is identified by choosing the highest RSI. The recursive simulations start with the largest possible number of successor companies, in this study we adopt the initial number of players on the modelling based on the market allocation according to PLN subsystems: 20 firms for Java-Bali power system and eight firms for Sumatra power system.

A. DC Load flow calculation

Based on DC power flow assumption, the power injection in node n is the difference between power generation production q_{Si} and consumer demand q_{di}. Thus, the power flow in the transmission line P_F could be denoted as a linear function between PTDF and $q_{si} - q_{di}$, $P_F = \sum_i PTDF(q_{si} - q_{di})$.

B. Demand function, supply function and elasticity

Marginal cost function $MC_i(q_{si})$ is the derivative of the total cost $TC_i(q_{si}) = f_i + c_i q_{si} + \frac{1}{2} d_i {q_{si}}^2; i = 1, \dots, I$. Thus, marginal cost is $MC_i(q_{si}) = c_i + d_i q_{si}$; $i = 1, \dots, I$. Inverse demand function is a linear function with negative slope $p_i(q_{di}) = a_i - b_i q_{di}; i = 1, \dots, I$. To calculate the inverse linear demand function for each node, we assume that the reference point for q_{di} is the peak load demand in each power system q_0. Price data from Indonesia Energy Ministry provides the price reference p_o. Based on the linear inverse demand function above, we provide the demand function as $q_{di} = \frac{a_i}{b_i} - \frac{p_i(q_{di})}{b_i}; i = 1, \dots, I$. The demand intercept $a_i > 0$ and slope $b_i > 0$, we calculate the elasticity of demand as $\varepsilon = \frac{\partial q_{di}}{\partial p_i(q_{di})} \frac{p_i(q_{di})}{q_{di}} = -\frac{1}{b_i} \frac{p_i(q_{di})}{q_{di}}$. $b_i = -\frac{1}{\varepsilon} \frac{p_0}{q_0}$; $a_i = p_0 - b_i q_0$.

C. Perfect competition modelling

Assume that $P_i(q_{di})$ is the energy consumption benefit; $MC_i(q_{si})$ is the total cost of generators at node i; q_{si} is the active load supply from generator at bus i and $\bar{q}_{si}$ is the available capacity of generator at node i. Under perfect competition modeling, the system operator seeks to maximize the consumer and producer surplus subject to the generation and transmission constraints. We formulate the ISO welfare maximization problem as:

$\max_{q_{di}} (\sum_i P_i(q_{di})\, q_{di} - \sum_i MC_i(q_{si}))$ Subject to the electricity demand balance $\sum_i q_{si} - \sum_i q_{di} = 0$, transmission constraint $\sum_l PTDF(q_{si} - q_{di}) \leq T_l$ and $-T_l \leq \sum_l PTDF(q_{si} - q_{di})$, generation constraint $q_{si} \leq \bar{q}_{si}$, and non negativity $q_{di} > 0$,$q_{si} > 0$.

D. Cournot imperfect competition modelling

Under Cournot competition, the total demand function is $P(Q) = \alpha - \beta Q$ in which Q is the total demand for an interconnected power system and P, is Cournot equilibrium price. The generation plants recognise their strategic interdependence and choose its output to maximize its profits, given its beliefs about the output strategy of its rivals. The profit function for generation at node i is defined by $\pi_i = \left(\alpha - \beta\left(\sum_{i=1}^{i=I} q_i\right)\right) q_i - \left(f_i + c_i q_i + \frac{1}{2} d_i {q_i}^2\right)$. The system operator seeks to maximise these profit functions resulting in optimality condition for each generation plant $\frac{d\pi_i}{dQ_i} = \alpha - \beta\left(\sum_{i=1}^{i=I} q_i\right) - \beta q_i - (c_i + d_i q_i)$. By setting the optimality condition in each node to zero, we have a matrix containing the variable q_i and the coefficients of the total demand and cost functions. The dimensions of the matrix depend on the number of generation plant in the network.

E. Marginal cost post-merger calculation

GenCo with multi-plant ownership behaves as a multi-plant monopolist where the marginal cost specifies each electricity generation from each plant. The combination of two power plants resulted in a horizontal addition of marginal cost function. The efficiency constant from merger process is 1. Thus, the GenCo pre-merger efficiency is equal to post-merger efficiency ($e_{pre-merger} = e_{post-merger}$). For two power plants with a linear marginal cost $mc_1 = c_1 + d_1 q_1$ and $mc_2 = c_2 + d_2 q_2$, the combining marginal cost is mc_{12} where $c_{12} = \left[\frac{c_1 d_2 + c_2 d_1}{d_1 + d_2}\right]$ and $d_{12} = \left[\frac{d_1 d_2}{d_1 + d_2}\right]$. The plants merger changes the initial marginal costs mc_i, and also supplier capacity k where $k_{12} = k_1 + k_2$.

F. Market power index RSI

We calculate market RSI as $r = \frac{k^T - k_{max}}{Q}$. Q is the total demand, k^T is the total generation capacity of the power system and k_{max} is the biggest supplier capacity in the market.

III. MODEL AND CASE STUDY

The current literature review on Indonesia power system is limited in the scope of Java-Bali and Sumatra power systems. Optimal power flow studies on Java-Bali power system was conducted by [1], [2], [3], while optimal power flow studies on Sumatra power system was conducted by [4]. [5] conducted the power system studies on the future interconnection of Sumatra-Java system through HVDC transmission system. The majority of this literature review discussed the technical aspect of the grid, i.e. load flow analysis, short circuit, and stability analysis. For example, [4] conducted a load flow, short circuit and transient analysis of power system interconnection between North System and Middle-South System on Sumatra's 275 kV transmission system. Although the current studies are limited in the engineering aspect, these studies contribute to the scientific modelling of this research. For example, optimal load flow studies provide an insight of the upper and lower boundaries of transmission constraint according to the load flow and transient stability analysis.

The economic model developed in this research is a pioneer one based on network subsystem boundaries set up by the PLN TSO's. The stylised model in this research does not precisely represent the complexity of Indonesia power system. However, we try to capture the crucial aspects of the system in the direction of constructing the ideal optimal market structure for Indonesia. Thus, stylised modelling, including demand and generation allocation for each node, is a crucial one and should incorporate all of the demands and suppliers in the system. The stylised model in the perfect competition and Cournot competition models did not change the original network configuration. The electricity market modelling in this research applies the law of parallel circuit to acquire accurate load flow and market power index determination. Figure 3 and 4 below shows the stylized model of Java-Bali and Sumatra power system.

The simulation setup in this research is limited to two power system interconnection, i.e. Java-Bali and Sumatra system. Sumatra and Java-Bali power system are not interconnected. Thus, the market modelling was conducted individually. We do not include Kalimantan, Sulawesi, Lombok power system and another isolated system, e.g. Papua since transmission lines are not connecting these regions (isolated regions). Also, Sumatra and Java-Bali power system already cover 86% of Indonesia power generation. We incorporate all power plants available, transmission and LSE in the system; and also simulate congestion analysis in perfect competition case.

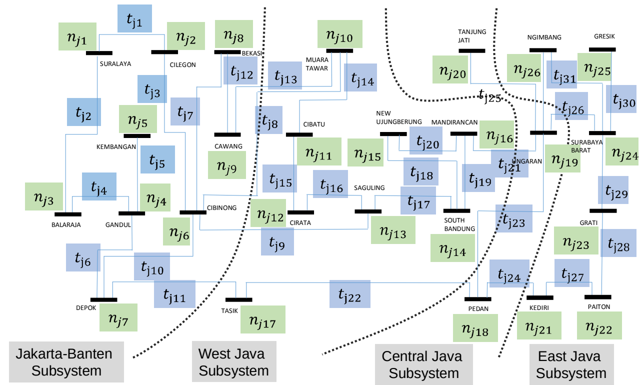


Figure 2. Stylised model of Java-Bali power system

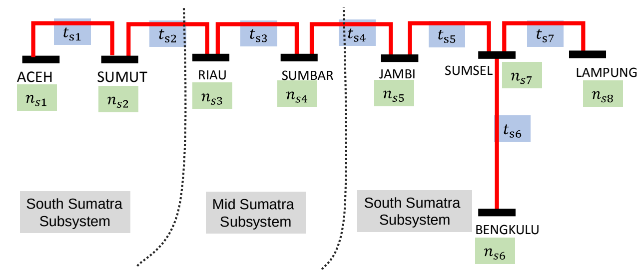


Figure 3. Stylised model of Sumatra power system

We collect all of the power system data from PLN according to the references in [6], [16], [17], [21], [22]. These power system data are publicly available datasets. PLN published these reports for power system planning, evaluation, and investment purposes. The list of data collections are as follows:

- Demand: Coincidence peak load for Java-Bali system and non-coincidence peak load for Sumatra system.
- Generation: Maximum and available capacity[1], PP and fuel type, fuel cost. We derived the linear marginal cost functions from a sample of heat rate curve of PLN's thermal PP.
- Transmission configuration and characteristic. We collect reactance and transfer limit to perform DC load flow analysis. This research applies stylised model based on the actual network configuration of 150 kV Sumatra system and 500 kV Java-Bali system. To acquire a precisely stylised model, we perform a model cross-checking with PLN TSOs. The reactance data is for a single circuit. Thus, the reactance rating for parallel cable is following the law of parallel-circuit.
- Load flow realisation. PLN TSOs conduct load flow analysis using power system software, e.g., Digsilent and PSSE. PLN provides the power system evaluation in [16], [17]. We adjust our base case scenario for constrained

[1] Availability capacity is the power plant capacity based on the availability factor, which is taking into account the curtailment/outages at a particular power plant. Availability factor often called capacity factor and represented the actual generation capacity of a power plant for given period.

nodal pricing based on power flow realisation from evaluation reports.

The generation system in this study includes the generations from PLN, IPP, and others than PLN and IPP, i.e. rental PP and excess power (e.g. excess power from Aluminum Plant in South Sumatra). The linear demand function was calculated according to the actual peak load for each node, assuming that the price elasticity of demand is inelastic for all areas. We derived generation cost from the adjusted quadratic function of the power plant's heat rate curve using power plant data, e.g. fuel price, fuel consumption rate and efficiency.

IV. Result and analysis

We simulate four case studies. Case 1 is Sumatra power system in normal operation. Case 2 is Sumatra power system in perfect competition in contingency N-1 (t_{s5}). Case 3 is Sumatra power system in Cournot competition. Case 4 is Java-Bali power system in normal operation. The issue of transmission constraint under Cournot competition is left for future studies. Solving equilibrium problems under strategic behaviours considering a large-scale system with network constraints are very hard to solve [12].

A. Case 1: Optimising Sumatra system in perfect competition

Table 3 Case 1 cascading configuration

Number of Companies	RSI	Cascading Configuration
7	0.76358234	1Merge7
6	0.76359713	6Merge8
5	0.76357604	4Merge6+8
4	0.76357603	3Merge4+6+8

B. Case 2: Sumatra in perfect competition contingency N-1

Table 4 Case 2 cascading configuration

Number of Companies	RSI	Cascading Configuration
7	0.76558923	1Merge7
6	0.76559245	3Merge6
5	0.76559611	4Merge8
4	0.76559558	3+6Merge4+8

C. Case 3: Sumatra system in Cournot competition

Table 5 Case 3 cascading configuration

Number of Companies	RSI	Cascading Configuration
7	0.83934074	4Merge7
6	0.83828574	1Merge3
5	0.83506934	6Merge8
4	0.83448581	1+3Merge5

D. Case 4: Java-Bali power system in perfect competition

Table 6 Case 4 cascading configuration

Number of Companies	RSI	Cascading Configuration
19	1.05939850	1Merge13
18	1.05976413	20Merge21
17	1.05990022	10Merge26
16	1.05973844	1+13Merge24
15	1.05980984	3Merge6

E. Analysis and Implications

We perform base case simulation with constraints and transmission congestions based on PLN power flow data year 2015 to derive the economic signals. As a base case, we model each subsystem as an individual player who represents one GenCo. Sumatra power system has eight players while Java-Bali power system has twenty players. Note that in Sumatra system, one GenCo only serves one LSE/subsystem. While in Java-Bali system, considering the loop connection complexity and voltage nominal variation, One GenCo could supply more than one LSE. On the other hand, two GenCos could serve one particular LSE.

The stylized models in this research do not adequately represent the real power system at a detail level of low voltage power substation. However, the modelling was based on the actual network topology of 150 kV and 500 kV power network by using a bottom-up approach. In Sumatra system, cable lines are connecting two power substation (SS) at the end of each node, i.e. transmission line t_{s1} is connecting 150 kV Langsa SS at n_{s1} Aceh with 150 kV Pangkalan Brandan SS at n_{s2} Sumut. Similarly, the stylised model in Java-Bali power system is according to the transmission line topology in 500 kV system where a node is equal to one 500 kV SS. Thus, the model will response in a similar way compared to the actual power system in responding to any changes in generation and demand.

Market power mitigation using residual supply index calculates market power by incorporates available capacity in the equation. Thus, market power monitoring using maximum capacity will compute a bias market index. There are two types of outages in the model, i.e. forced and planned outages. The forced outage is the estimated loss of generation due to unplanned activities, e.g. fire, lighting, flood, a fallen tree that caused tripped overhead or underground lines. The planned outage is the estimated loss of generation due to planned maintenance activities by power system operator. The availability factor in this model is taking into account the two types of outages above for the year 2015. For power plants that operate at the year 2015, the availability factor is also taking COD time into the calculation, i.e. the actual time when the power plant energies and supply electricity to LSEs. Note that this model assumes the Hydropower plant to operate in the maximum capacity as in wet season.

The optimal mix of generation plants of successor companies under perfect companies is substantially different to Cournot competition. Equilibrium demand is higher in perfect competition compare to Cournot competition. Thus, the RSI is higher in Cournot competition contrast to the perfect competition. The cascading configuration in perfect competition and perfect competition is different. Let us compare the case study 1 and 3 (See Tables 3 and 5). In perfect competition. The optimal market structure for seven players configuration in Sumatra power system is when player 1 combine with 7, while in Cournot competition the optimal market structure exists when player 4 combines with player 7. The cascading configuration also different for the following cascading configuration in 6, 5, and four players' configuration.

Another main result is that the optimal mix of generation plants is affected by transmission constraint as we can compare the results in Tables 3 and 4. Power system constraints consist of transmission constraint that reflects the flow of active power and voltage constraints which affects the optimal configuration of successor companies. Sumatra power system suffers several power system constraints, i.e. transmission limit, small-signal stability, transient stability and subsystem interconnection[2]. Transmission constraints T_l reflect the cable thermal limit for 150 kV overhead transmission lines. Small-signal stability constraint reduces the transfer limit of t_{s5} which connect the South and Mid Sumatra subsystem to 230 MW. Interconnection constraint between North and Mid Sumatra subsystem limit the cable limit of t_{s2} to 90 MW which reflects the actual demand in the nearest substation. Thermal constraint in t_{s7}, and stability constraints in t_{s5} are normally binding and have an impact on the prices since Sumsel subsystem transport lower energy price compare to the importer subsystems (Lampung and Jambi). Indonesia policy maker, facing the risk of an N-1 contingency, could customise the size, location, and technology of generation plants of successor companies to establish the optimal electricity market structure in Indonesia by eliminating the anticompetitive effect of transmission constraints.

V. Conclusion

In the process of electricity market restructuring, successor companies normally created from the divestiture of monopoly state-owned electricity company. However, history shows that the poor divestiture creates excessive market power exercise. We conduct nodal market simulation under perfect and Cournot competition on Java-Bali and Sumatra power system. Our modelling approach based on Residual Supply Index, a widely used market power index for competition policy in the restructured electricity market. Our findings provide suggestions to Indonesia's energy stakeholders for actionable guidelines on how to design the efficient configuration of successor companies that influenced by the size, location, and technology of constituent generation plants of successor companies.

Acknowledgment

The views expressed herein are ours and do not necessarily map to those of our institutional affiliations. The authors are grateful for the funding from the Indonesia Endowment Fund for Education and the support of PLN.

References

[1] I. M. Wartana, J. G. Singh, W. Ongsakul, and N. P. Agustini, "Optimal placement of a series FACTS controller in Java-Bali 24-bus Indonesian system for maximizing system loadability by Evolutionary Optimization Technique," *Proc. - 3rd Int. Conf. Intell. Syst. Model. Simulation, ISMS 2012*, pp. 516–521, 2012.

[2] Y. Tarid, M. Cahyono, K. Yamashita, M. Nurdin, and N. Hariyanto, "Insertion of 275 kV Network in Jawa Bali System-jakarta Area Case Study," *Procedia Technol.*, vol. 11, no. Iceei, pp. 250–256, 2013.

[3] I. B. Sulistiawati, M. Abdillah, and A. Soeprijanto, "Neural network based transient stability model to analyze the security of Java-Bali 500 kV power system," *Proc. 2011 Int. Conf. Electr. Eng. Informatics*, no. July, pp. 1–6, 2011.

[4] D. F. Hakam, R. Wahyuni, and E. Y. Pramono, "Switching study for 275 kV Padang Sidempuan-Payakumbuh Transmission Line," in *2011 International Conference on Electrical Engineering and Informatics*, 2011, no. July 2011, pp. E10-3.

[5] R. Faizal, M. Nurdin, R. Faizal, and S. Pack, "Sumatra-Java HVDC Transmission System Modelling And System Impact Analysis," *PowerTech*, 2015.

[6] PLN, "Rencana Umum Penyediaan Tenaga Listrik (National Electricity Supply Business Plan) PT PLN (Persero) 2015-2024," Jakarta, Indonesia, 2015.

[7] D. Hakam, "Optimizing the mix and structure of successor companies in electricity market restructuring," in *39th IAEE International Conference*, 2016, pp. 1–20.

[8] D. F. Hakam and R. Macatangay, "Optimising Market Structure using Market Power Mitigation and Forward Contract in Electricity Market Restructuring," in *40th IAEE International Conference*, 2017, pp. 1–40.

[9] F. Schweppe, M. Caramanis, R. Tabors, and R. Bohn, *Spot Pricing of Electricity*, 1st ed. Massachusetts: Kluwer Academic Publishers, 1988.

[10] R. Macatangay, "Space-Time Prices of Wholesale Electricity in England and Wales," *Util. Policy*, vol. 7, no. 3, pp. 163–188, 1998.

[11] R. Green, "Nodal pricing of electricity: How much does it cost to get it wrong?," *J. Regul. Econ.*, vol. 31, no. 2, pp. 125–149, 2007.

[12] F. U. Leuthold, H. Weigt, and C. von Hirschhausen, "A Large-Scale Spatial Optimization Model of the European Electricity Market," *Networks Spat. Econ.*, vol. 12, no. 1, pp. 75–107, 2012.

[13] B. Willems, I. Rumiantseva, and H. Weigt, "Cournot versus Supply Functions: What does the data tell us?," *Energy Econ.*, vol. 31, no. 1, pp. 38–47, 2009.

[14] L. B. Cunningham, R. Baldick, and M. L. Baughman, "An Empirical Study of Applied Game theory: Transmission Constrained Cournot Behavior," *IEEE Trans. Power Syst.*, vol. 17, no. 1, pp. 166–172, 2002.

[15] S. Hagspiel, C. Jagemann, D. Lindenberger, T. Brown, S. Cherevatskiy, and E. Troster, "Cost-optimal power system extension under flow-based market coupling," *Energy*, vol. 66, pp. 654–666, 2014.

[16] P3BS, "Operation evaluation year 2015: Sumatra power system," Pekanbaru, Indonesia, 2016.

[17] P2B, "Operation evaluation year 2015: Java-Bali power system," South Jakarta, indonesia, 2016.

[18] A. Sheffrin, "Critical Actions Necessary for Effective Market Monitoring : Draft Comments of Anjali Sheffrin FERC RTO Workshop, OCtober 19, 2001," California, USA, 2001.

[19] A. Sheffrin, "Predicting Market Power Using the Residual Supply Index. Presented to FERC Market Monitoring Workshop December 3-4, 2002," California, USA, 2002.

[20] A. Rahimi and A. Sheffrin, "Effective Market Monitoring in Deregulated Electricity Markets," *IEEE Trans. Power Syst.*, vol. 18, no. 2, pp. 486–493, 2003.

[21] P2B, "Operation planning year 2016: Java-Bali power system," South Jakarta, indonesia, 2016.

[22] P3BS, "Operation planning year 2016: Sumatra power system," Pekanbaru, Indonesia, 2016.

[2] North Sumatra and Mid Sumatra subsystem were interconnected in 2007 through 150 kV T/L Bagan Batu - Kota Pinang. However, due to stability issue arises from interconnecting the two subsystem, the system remains separated. The line connecting this two subsystem is operated in normally-open condition. See [4] for further explanation regarding transient stability and interconnection problem in Sumatra power system.